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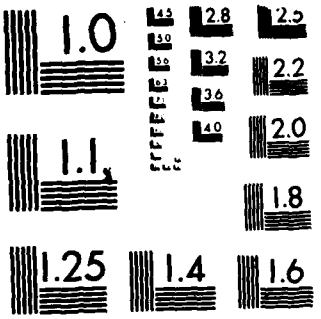

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FIELD	GROUP	SUB GR	Spread spectrum; M-ary DPSK, intersymbol interference, power imbalance; noise correlation; satellite repeater channel; asymptotics; differential phase statistics; jamming.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Five papers have been prepared under this contract in which recently developed differential phase statistics have been successfully employed to obtain error rate performance of differential modulation systems operating under practical conditions. These practical conditions included power imbalance, phase-change offset, noise correlations and intersymbol interference. The modulation systems considered were binary conventional and symmetric DPSK, offset DPSK, and M-ary DPSK. The channels studied were both terrestrial and satellite. Closed form expressions, requiring some numerical integration, were obtained in all cases. Extensive performance curves showing the effects of the various impairments were presented. Because satellite link performance depends strongly upon the qualities of the uplink, as shown, it was concluded that a satellite repeater is much less effective than a detect and remodulate transponder in a severe jamming environment. Asymptotic approximations to M-ary DPSK were shown to be extremely good, and it was suggested that more emphasis be placed on such methods as opposed to the more traditional, but much less accurate, use of bound

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INTERIM REPORT

APPLICATIONS OF DIFFERENTIAL PHASE STATISTICS TO STUDIES OF C^3 AND SPREAD SPECTRUM COMMUNICATIONS

(a) Statement of Work

(i) Spread spectrum modulation techniques. Investigate spread spectrum techniques for operation under realistic conditions. Develop bit error rate expressions for differential modulation in the presence of impairments such as intersymbol interference, power imbalance, noise correlation, timing, tracking and frequency errors, fading, and certain types of jamming.

(ii) New mathematical approaches. Develop novel mathematical techniques or approaches if needed to successfully attain the above goals.

(iii) Quantitative results. Calculate and tabulate, or present in graphs, the desired operating characteristics for typical realistic parameter values. Compare results with previous analytical work of other researchers. Prepare reports so that they will be suitable for submission to scholarly technical journals.

(b) Status of Research Effort

Most of the objectives in the above statement of work have been attained in the five publications written under this contract and listed in the next section. In Paper No.1, much simplified forms for the bit error rate performance of binary differential phase shift keying (DPSK) modulation on terrestrial and satellite channels were obtained in the presence of noise correlation and power imbalance. In Papers No.2 and 4, these results were extended to the more general case of binary DPSK with phase-change offsets, power imbalance and noise correlations. A new detector was introduced that employed knowledge of the noise correlation to give a performance improvement over the classical detector for DPSK which does not take the noise correlation into account. Also, optimum phase-change offsets were investigated and conventional and symmetric DPSK were compared. All of these cases were generalized in Paper No.5 which investigated M-ary DPSK modulation in the presence of phase-change offsets, power imbalance and noise correlation for both terrestrial and satellite channels, and a solution was outlined in detail for the treatment of intersymbol interference effects. Although the timing, tracking and frequency errors were not specifically examined, they can also be handled by use of the basic theory developed for the the phase-change offset and power imbalance in Paper No.5. Fading was not treated in any of the published papers, but progress has been made in initial studies which show that the fading analyses will be greatly simplified as a result of the simplified integral expressions for the error rates obtained in the published papers. Jamming was treated to the extent of its qualitative effect on the design of a satellite transponder in Paper No.5.

Novel mathematical techniques have been proposed and examined from the standpoint of giving more emphasis to asymptotic methods than has been commonly done in the past by others, and the accuracy of such methods was explored in Paper No. 3. It was found, somewhat surprisingly, that the asymptotic results

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are accurate to within a few percent over the entire range of signal-to-noise ratios of interest (above 1 dB). The new differential phase statistics of Pawula, Rice and Roberts were applied in Papers No. 1, 2, 4 and 5 to give bit error rate expressions in a form suitable for computation on a hand-held portable computer such as the Sharp PC-1500. The formulations for the error rates using these methods in the M-ary case in Paper No. 5 are completely new.

Although some bit error rate curves were given in Papers No. 2 and 4 for the case of binary DPSK, much more extensive operating curves were presented in Paper No. 5 in which numerous bit error rate curves are given for binary, quaternary, octal and 16-ary DPSK modulations over the terrestrial channel, and binary, quaternary and octal modulations over the satellite channel. Indeed, the fact that Paper No. 5 contains both extensive theoretical results as well as extensive design curves is felt to be one of its strong points. In all of the papers, comparisons were made with results of previous researchers, but mostly so in Paper N. 5 because of its nature. All of the above papers have either been published or are in press in scholarly technical journals.

In summary, although important strides have been made and much work has been done under the support of this contract, the results need yet to be applied to studies of timing, tracking and frequency errors, fading, and certain types of jamming.

(c) List of Written Publications in Technical Journals

1. R.F. Pawula and J.H. Roberts, "The Effects of Noise Correlation and Power Imbalance on Terrestrial and Satellite DPSK Channels," IEEE Transactions on Communications, COM-31, pp. 750-755, June 1983.

2. R.F. Pawula, "Offset DPSK and a Comparison of Conventional and Symmetric DPSK with Noise Correlation and Power Imbalance, "Proceedings of MILCOM '83, Washington, D.C., pp. 93-98, October 1983.

3. R.F. Pawula, "Asymptotics and Error Rate Bounds for M-ary DPSK," IEEE Transactions on Communications, COM-32, pp. 93-94, Jan. 1984.

4. R.F. Pawula, "Offset DPSK and a Comparison of Conventional and Symmetric DPSK with Noise Correlation and Power Imbalance," IEEE Transactions on Communications, COM-32, pp. 233-240, March 1984.

5. R.F. Pawula, "On M-ary DPSK Transmission Over Terrestrial and Satellite Channels," IEEE Transactions on Communications, COM-32, July 1984 (in press).

Paper No. 2 above is an abridged version of Paper No. 4. It had to be shortened by about a third which necessitated the deletion of some of the material as a result of the page limit requirements imposed by the editors of the conference proceedings.

(d) List of Professional Personnel Associated with Research Effort

All of the papers written under this contract were written by the Principal Investigator, Dr. Robert F. Pawula. Paper No. 1 was done with the colaboration of Mr. John H. Roberts of the Plessey Electronics Company, Roke Manor, Romsey, Hampshire, England SO5 OZN, and was an outgrowth of the earlier joint paper with S.O. Rice:

> R.F. Pawula, S.O. Rice and J.H. Roberts, "Distribution of the Phase Angle Between Two Vectors Perturbed by Gaussian Noise," IEEE Transactions on Communications, COM-30, pp. 1824-1841, August 1982

On-going correspondence is maintained with Dr. Rice and Mr. Roberts concerning various mathematical aspects of the work performed under this contract.

(e) Interactions (Coupling Activities)

(i) Papers presented at meetings. The Principal Investigator attended the 1983 IEEE Military Communications Conference in Washington, D.C., October 1983 (see Paper No. 2 above) and the 1983 IEEE GLOBECOM Conference, San Diego, November 1983.

(ii) Consultative functions to other agencies. The Principal Investigator consults on an on-going and informal basis with Dr. Marvin K. Simon of the Jet Propulsion Laboratory of NASA on problems dealing with the mathematical aspects of differential modulations, and has been acknowledged in several recent publications by Dr. Simon for assistance. The Principal Investigator has reviewed papers for the IEEE Transactions on Communications, the IEEE Transactions of Information Theory and the Mathematics of Computation during the course of this contract.